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ON THE

MANNER OF DEPOSIT OF THE GLACIAL DRIFT.

By O. P. Hay.

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362
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ART. VII.—*On the manner of Deposit of the Glacial Drift;* by O. P. HAY.

THE events of the "Great Ice Age," that period of the earth's history during which the deposits known as the "Drift" were scattered over a great portion of the Northern Hemisphere, have left many problems to perplex and to reward geologists, physicists, and astronomers. Some of these problems have already been solved; many yet await solution. That the principal agent concerned in performing this vast work was glacial ice; that its general direction of movement was from the north toward the south; and that it bore along with it, often from very distant localities, the materials of the Drift, are conclusions that are now pretty generally conceded. A problem whose solution has not yet been effected, is that relating to the manner in which the great glacial ice-sheet has deposited upon the older rocks its burden of materials that it had wrested from the strata and mountains farther north. There seems by no means to have been any dearth of theories on the subject, but none of them have been able to command general assent.

Prof. J. D. Dana has held the view that the materials of the drift were gathered up during the Glacial period, and for the most part deposited by the melting of the ice during the Champlain. His language is as follows:

"The earlier part of the Champlain period was the era of the melting of the great glacier and of most local glaciers . . . . and of the deposition of the sand and gravel of the glacier, except the relatively small part which had been earlier dropped," etc.—*Manual*, 1876, p. 542.

Prof. James Geikie appears to adopt the hypothesis that the Drift deposits accumulated under the glacier, but I am not aware that he has anywhere attempted to tell us how. His language in various passages seems to imply that these materials thus lying beneath the glacier were either constantly being pushed along or, at least, liable thus to be acted upon by

the moving ice. Dr. Archibald Geikie evidently holds similar views. He says:

"Underneath the great ice-sheet, and perhaps partly incorporated in the lower portions of the ice, there accumulated a mass of earthy, sandy, and stony matter (till, bowlder-clay, 'grund-moräne,' moraine-profonde, older diluvium') which, pushed along and ground up, was the material wherewith the characteristic flowing outlines and smoothed striated surfaces were produced."—*Text-book of Geology*, Ed. 1885, p. 894.

Again in a foot note on the same page, he says:

"It is difficult to explain by any known glacial operation, the accumulation of such deep masses of detritus below a sheet of moving land ice. Another problem is presented by the occasional and sometimes extensive preservation of undisturbed loose pre-glacial deposits under the till. The way in which the Forest-bed group has escaped for so wide a space under the Cromer cliffs with their proofs of enormous ice movement, is a remarkable example."

In our own country Profs. J. S. Newberry and N. H. Winchell have been most explicit in the enunciation of their views on this subject. Both are oppressed with the difficulties that lie in the way of understanding how the till can have accumulated under the moving glacier. The latter (Pop. Sci. Monthly, 1873, 293), puts forward the proposition that through the action of winds bearing dust and through the melting of the upper surface of the glacier, the materials now constituting the Drift accumulated on the surface of the ice sheet, and were either carried forward to the terminal edge and deposited there or, on the decay of the glacier, let down quietly on the rocky surface below. He has more recently re-affirmed these views (this Journal, 1881, 358), in calling attention to some of Capt. Dall's observations made on the coast of Alaska. There has been discovered in that region a sheet of ice of unknown extent and great thickness, that bears on its surface a thin soil, in which there is found growing in some places a rather luxuriant forest vegetation. In holes in this soil and in the underlying ice, there occur, besides decaying animal and vegetable matter, the bones of mammoths, buffaloes, etc.; and from these we may judge of the vast age of this stratum of ice. This is regarded by Prof. N. H. Winchell as being a "fossil glacier," the counterpart of which once spread over a considerable portion of our Northern States.

Prof. J. S. Newberry, in the volumes of the Geological Survey of Ohio, and elsewhere, insists strongly that the Drift materials could have accumulated neither on the surface of the great glacier, nor in any considerable thickness beneath it;

but that they were carried along in and under the glacier, and finally deposited as a terminal moraine, which, by the slow retreat of the glacier to the north, at length became a continuous sheet.

That wind, blowing for long ages over the glacier from the region lying to the south and west, may have deposited on it more or less dust; and that superficial melting may have brought some coarser materials to the surface, are suppositions that are entirely probable. The "shearing action" of the moving glacier may also, as H. Carville Lewis has recently shown us, have brought a certain amount of sand, gravel and bowlders from the lower portions of the glacier to the surface. But all these agencies combined probably did not result in producing any considerable superficial deposit. We cannot calculate on the dust with any confidence. Moreover, when once a thin covering of *debris*, from whatever source, had accumulated over the ice, it would protect this from further melting, and thus cut off one important source of addition. The intestinal motion of the glacier, too, would in all probability contribute little materials, on account of the sluggish movement of the glacial mass as a whole. As regards Capt. Dall's fossil ice-sheet, it cannot, in all probability, have any motion now, or have had any since the days of the mammoth; otherwise all those fossil bones would long ago have been shot out into the Arctic Ocean.

Against the theory that the bowlder-clay accumulated under the glacial sheet, Prof. Newberry makes protest on the ground that the underlying rocks show that the ice was in close contact with them, being separated from them by, at most, a thin stratum of sand and gravel. He says:

"It did not accumulate *beneath* the glacier, because the rock surface on which it rests, is planed down, grooved and carved, as it could only be when the ice fitted closely to it; and since two solid bodies cannot occupy the same space at the same time, the clay could only have accumulated in the places where it is found, after, or as, they were abandoned by the ice."—*Geol. Sur. Ohio*, vol. iii, 34."

Again (Geol. Sur. Ohio, vol. ii, 29):

"That the bowlder clay was not deposited *beneath* the glacier, as sometimes stated, is apparent from the fact that it covers the glaciated surface on which the ice rested, in a sheet sometimes a hundred feet in thickness. *It must, therefore, have accumulated at the margin of the glacier.*"

To these arguments it seems to me sufficient to reply that it is not necessary for us to suppose that, in order to produce all the observed effects on the underlying rocks, the ice-sheet continued to move over and in immediate contact with them dur-

ing *the whole Glacial period.* At the beginning of that period the ice with its enclosed bowlders and sand, did undoubtedly pass over the old surface and plane it down and groove it; but later there may have intervened between the glacial ice and this eroded surface a greater or less thickness of bowlder clay. Of course, some trouble may be experienced in comprehending how great glaciers thousands of feet in thickness and exerting a downward pressure of probably 50,000 pounds to the square foot* and containing sand, gravel and bowlders could move over deposits of bowlder clay, and instead of eroding them, continue to make additions to them.

This and many other difficulties have arisen from pushing too far the usually good practice of interpreting the events of the past by what we see occurring in our own day. At the present, we are acquainted with no glaciers except such as flow down steep inclines and terminate on such inclines either by melting or breaking off in the sea. On the other hand, the glaciers that deposited the Drift materials of the Western States after descending from the elevated regions of Canada, deployed out on nearly level plains for hundreds of miles. It is quite improbable that such a glacier would erode its bed and deposit its detritus in the same way that a Swiss glacier does. We could, perhaps, determine as correctly the eroding, transporting and depositing effects of running water by studying a roaring Alpine brook, as we can judge of the phenomena that attended the movements of the ancient ice-sheet by studying the Mer de Glace. But we know that the stream that in one part of its descent wears away the hardest rocks and bears along with it in its impetuous course, gravel and stones, may in its lower reaches, deposit the most impalpable sediments, and move so gently as not to disturb the most delicate leaf that may have fallen on its bed.

In like manner, as the glaciers of the Ice Age descended from the Laurentian Mountains and ploughed through the narrow channels now occupied by the Great Lakes, their eroding action was incessant and irresistible; but when those great streams of ice were spread out over Ohio, Indiana and Illinois, they became far less destructive. But even here, and however slow the motion, the underlying deposits were in most places worn away. But the soils and other deposits in depressed places of small area and behind cliffs of rocks probably would not suffer much erosion; since there the upper layers of the ice would flow on over the stationary lower layers. In this way we may account for the preservation of the soils and the contained remains of trees in the Cromer Forest-bed and for the abundant remains of trees and old soils below and even

* Newberry, Pop. Sci. Monthly, November, 1886.

in the Drift. In some cases such deposits may have been protected from glacial action by thick accumulations of compacted snow and ice which heralded the approach of the glacier.

While we may justly, I think, consider the eroding action of a glacier, like that of a running stream, to be some function of its velocity, the same cannot be said of the transporting and depositing powers of the glacier. When the velocity of the stream is reduced even a little, a portion of the materials it bears along may be deposited; but stones, large and small, once received into the bosom of the glacier are borne along, whatever may be the velocity. Yet we have evidences which show that in some cases bowlders have sunken in the glacial ice, so that they have, as Prof. J. D. Dana relates, got into a lower current running in a different direction. This is no more than we might expect of heavy rocks that are supported in a mass of ice which is constantly undergoing incipient liquefaction and regelation; and we may suppose that this tendency of rocks to gravitate downward would, in a slowly moving glacier, prevail over the tendency of the intestinal motion to throw them upward. However, it is not probable that these movements have had much to do with the making of the Drift deposits, to account for the enormous mass of which we must have recourse to other facts and principles.

What is known as the law of differential motion prevails in all glaciers. This law is a statement of the fact that different portions of the glacial stream move with very different velocities, the upper portions faster than the lower, the middle of the stream faster than the edges. The velocity of flow of the lower parts must be affected greatly by the character of the bed, and by the relative quantities of foreign materials enclosed.

There is another fact which must be considered at this point, namely, that there is in all glaciers more or less melting going on at the bottom. The sun's rays may cause the surface of the ice to thaw and waste away, but the heat that escapes from the earth must expend its energy in melting the bottom of the glacier. This action of the terrestrial heat is recognized by glacialists, and produces what is known as subsidence of the glacier. Accordingly we find streams of water escaping from beneath even the glaciers of the polar regions. The inevitable result of this melting of the lower layers of a slowly moving ice-stream must be to cause the rocks, sand and clay to accumulate in greater proportions in its lower parts. If we now connect this conclusion with the law of differential motion, we shall, I think, be able to account for the deposit known as the bowlder clay. While the great glacial ice-sheet of North America was descending from the Laurentian Highlands, where it took its origin, its weight was so enormous and its velocity

so great, that it powerfully denuded those regions and, bearing the *debris* along with it, constantly exposed a new surface to erosion. As it was urged on over the region of the present Great Lakes and was confined to comparatively narrow channels, it continued to gather up the wreck of the abraded strata below; but when it had debouched from these channels and had become spread out into a much broader sheet, its motion was much slower, and its pressure on the underlying strata much less than formerly. As it *was* in motion, however, it at first planed off the surface of all parts of the country that were not specially protected, and polished and scored the underlying rocks, as we find them to-day. But the earth's heat was constantly invading the lower layers of the glacier and melting it away. Thus it would happen that a larger and larger proportion of heavy materials would accumulate at the bottom of the ice-sheet. Stones would also doubtless often reach the bottom through crevasses, and streams of water from superficial melting would carry thither sand and clay.

It can scarcely be doubted that this accumulation of coarse, earthy, materials in the lower portions of the glacial mass would greatly retard the movement there; and with the increase of these materials, the retardation would go on until a time would come when all movement in those lower layers would cease, the small proportion of ice be melted out, and a permanent deposit formed. Other horizons higher up would then in their turn be similarly affected; and thus the bottom moraine might attain almost any thickness.

While contending that the great bulk of the Drift deposits were formed as above described, we may believe with Prof. Newberry and others that much of the glacial *debris* was carried forward and deposited in terminal moraines; and recently a number of these moraines have been described by Profs. Chamberlain and Wright, and others. We may again believe with Prof. J. D. Dana that large quantities of detritus were held in the body of the glacier and deposited on its final dissolution during the Champlain. Such a deposit, not having been subjected so long to the grinding action of the glacial mill, would naturally contain more and larger stones than the deeper parts of the Drift. Nor are we precluded from believing with Prof. N. H. Winchell that there may have been, here and there, tracts of soil visible on the face of the wide extended whiteness.

The conclusions reached above may be thus summed up:

1. A glacial ice-sheet moving over a nearly level surface would possess far less power of abrading its bed than the same glacier would have while descending a slope of high angle.

2. Through subsidence of the glacial mass, caused by the earth's heat, and through other influences, a constantly increas-

ing proportion of inert materials would collect in the lower layers of the moving ice.

3. The accumulation of such materials would tend to retard the motion of the lower portions of the glacier; and finally, when they formed a sufficiently great proportion of the mass, all motion of the lower portion would cease and a permanent deposit would begin and continue to be made.

4. Other masses of detritus might be deposited at the foot of the glacial ice-sheet as a terminal moraine, and still other masses on the top of the already formed deposit when the glacier finally melted.